

GROUND REACTION FORCES IN 1G AND SIMULATED ZERO-GRAVITY RUNNING

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INTRODUCTION

This research compared ground reaction forces during overground (1G) running and zero-gravity (0G) simulated treadmill running at a full body weight load in two restraint harness designs.

REVIEW AND THEORY

Exercise will almost certainly play an integral part in minimizing the bone mineral loss and muscular atrophy that occur during spaceflight. It is hypothesized that an effective exercise regimen would elicit loads on the lower extremities that resemble those on Earth (Convertino and Sandler, 1995). No on-orbit testing has yet quantified the forces to which the lower extremity has been exposed, but it is believed that, to date, these forces have been much less than the forces experienced in 1-G (Cavanagh, 1987).

The Penn State Zero-Gravity Simulator (PSZS Davis et al. 1996) is a device which suspends subjects horizontally from multiple latex cords, with each cord negating the weight of a limb segment. A treadmill mounted on the wall under the PSZS enables subjects to run in simulated 0G. Subjects wear a harness to which a number of springs, which provide a gravity replacement load, are connected. The opposite end of each spring is connected to the side of the treadmill. During exercise, astronauts currently wear a similar harness in which the spring tethering load pulls at both the waist and shoulders (Greenisen and Edgerton, 1994).

The purpose of this study was to compare ground reaction forces from subjects wearing one of two harness designs under a 100% BW load in the PSZS with data from the same subject running across the laboratory floor. The objective was to gain insight into the effectiveness of the present exercise countermeasures for bone mineral loss and muscular atrophy in space.

PROCEDURES

Sixteen subjects (age 22.9 ± 6.9 yrs, height 178.1 ± 6.68 cm, and mass 72.8 ± 5.8 kg) participated in this study. Subjects ran at 2.68 m/s. One Kistler force plate recorded normal force data as subjects ran across the laboratory floor and another, mounted within the treadmill belt, measured normal ground reaction forces of subjects in the PSZS. Two PSZS subject load configurations were assessed: a "shoulder only" design (SSO), in which 4 springs were attached to shoulder pads worn by the subject, and "waist and shoulder" design (WSS), in which 4 springs were attached to the shoulder pads and 4 to a waist harness. Load cells measured tension in the springs. Data were collected at 500 Hz.

RESULTS

All subjects could tolerate a 100% body weight load applied through the harness. The maximum active force was significantly greater in the 1G condition, although the timing of this event was the same in all conditions (Figure 1, Table 1). The magnitude of the passive peak was similar in all conditions, but this peak occurred earlier in the PSZS conditions, resulting in a significantly greater loading rate. The impulse was greater in the 1G condition.

Table 1: Ground Reaction Force results

	1G	SSO	WSS
Max. Active GRF (%BW)	*240.61 ± 7.04	180.04 ± 3.77	159.75 ± 3.97
% stance Max Active GRF	43.57 ± 2.89	43.80 ± 1.60	43.99 ± 1.64
Max. Passive GRF (%BW)	159.29 ± 7.34	161.84 ± 3.90	150.08 ± 4.01
% stance Max Passive GRF	*15.01 ± 1.11	10.64 ± 0.59	10.07 ± 0.60
Load Rate (BW/sec)	40.60 ± 2.85	*51.97 ± 1.52	*51.81 ± 1.57
Impulse (BW sec)	*0.41 ± 0.14	0.33 ± 0.01	0.30 ± 0.01

* indicates that $p < 0.01$

The tension in the tethering springs fluctuated by $17.89 \pm 1.25\% \text{BW}$ in the SSO condition and $36.83 \pm 1.30\% \text{BW}$ in the WSS condition as the subject's COM oscillated toward and away from the treadmill surface. The average subject load was $96.36 \pm 1.59\% \text{BW}$ in SSO and $88.95 \pm 1.66\% \text{BW}$ in the WSS condition. The flight phase impulse in the 1G was only approximately 87% of the flight phase impulse in the PSZS conditions.

DISCUSSION

The maximum force occurred at approximately the time of the minimum subject load (Figures 1 and 2), which was less than body weight at this time. The subject was pushing off less because a smaller force was needed to overcome the "gravitational" load. If the force curves are normalized to the gravity in 1G or the instantaneous subject load in the PSZS instead of body weight, the curves look similar in all conditions, as shown in Figure 3.

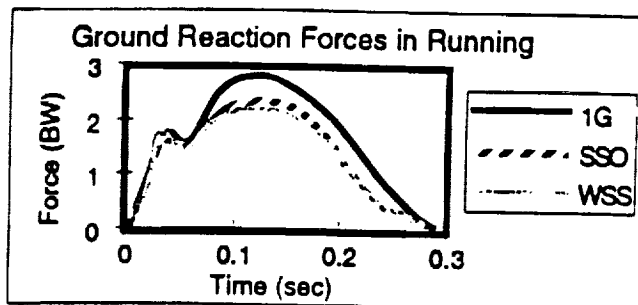


Figure 1: Representative ground reaction force curves from the running conditions.

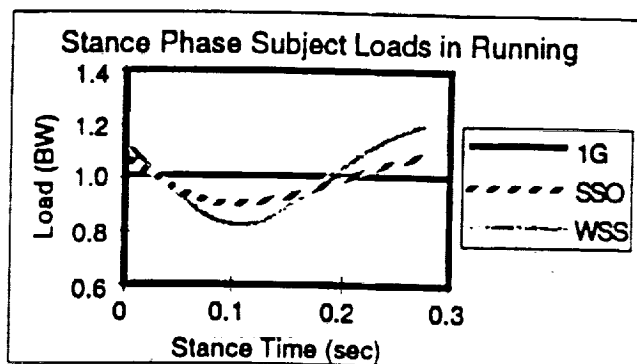


Figure 2: Representative subject load curves during the stance phase of running.

Because the flight impulse was greater in the PSZS conditions, the subject had a higher impact velocity - resulting in a greater loading rate.

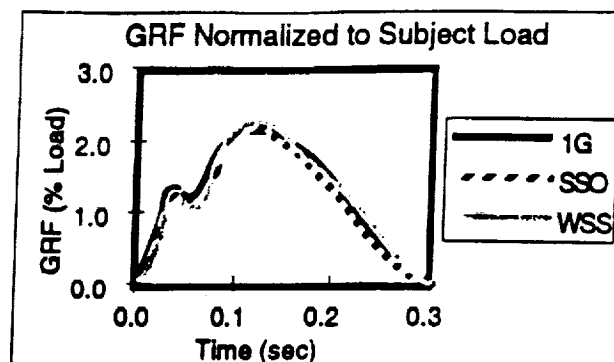


Figure 3: Maximum ground reaction force, for one subject, normalized to subject load instead of body weight.

The conclusions of this study are entirely dependent upon what aspects of the 1G forces are important for maintaining bone and muscle. If the aim is to equal 1G peak forces (Whalen et al., 1968), the fluctuation of subject load should be minimized since this appears to be responsible for required normal GRFs during mid-stance. If it is greater loading rates that result in increased bone density (Lanyon and Rubin, 1984), then fully loaded 0G treadmill exercise will be effective as long as it is of the necessary duration.

ACKNOWLEDGMENTS

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